NGL-39-009-02[illegible]

PSU-SCL-17(74)

THE PENNSYLVANIA STATE UNIVERSITY
COLLEGE OF ENGINEERING

SYSTEMS AND CONTROLS LABORATORY

RESEARCH REPORT NO. 17 UNIVERSITY PARK, PA. OCTOBER, 1974

(NASA-CR-142645) [RESEARCH ON FLUIDICS, VALVES, AND PROPORTIONAL AMPLIFIERS] (Pennsylvania State Univ.) 12 p HC $3.25 CSCL 13G
N75-21555
Unclas
G3/34 18617

THE SYSTEMS AND CONTROLS LABORATORY

The Systems and Controls Laboratory was started in 1964 to encourage graduate research and development on engineering systems, with emphasis on improving the understanding of basic elements and devices and bridging the gap between theory and practice. The experimental equipment and facilities of this systems laboratory have been provided for carrying out experimental investigations on devices and systems involving many of the different engineering disciplines. Staff members, graduate fellows, and graduate assistants are now working on projects and thesis topics of vital interest to engineers concerned with the advanced design and development of new engineering systems.

Much of the work involves mathematical and computer modeling and analysis and the experimental investigation of breadboard and prototype systems or devices. A major goal of this work has been to accomplish a useful synthesis of analytical and experimental methods in research and development of advanced engineering systems for effective use by engineers and scientists working on future aerospace systems.

Financial support for this program is derived from the University, the National Aeronautics and Space Administration, and the Harry Diamond Laboratories. A major share of the projects in the Systems and Controls Laboratory are supervised by Dr. J. L. Shearer, Rockwell Professor of Engineering, assisted by other members of the graduate faculty.

CONTENTS

STATIC CHARACTERISTICS OF LAMINAR PROPORTIONAL AMPLIFIERS

Gary V. Smith, Graduate Assistant in M. E.

On-going research in the SCL is concerned with determining both experimentally and analytically the response characteristics of laminar proportional amplifiers. As previously reported [16], the first phase of this research effort was to qualitatively study the phenomena involved with laminar jet amplification by means of flow visualization of large-scale working models of the laminar-jet amplifier.

The second phase of the experimental portion of this program was to determine the static characteristics of the amplifier shown schematically in Fig. 1. The amplifier model was composed of stacked laminates having a supply nozzle exit width of 2.54 mm. The physical size of the element and the working fluid (MIL-H-5606) were chosen so that easily measured flow rates and pressures could be obtained. All pressures were measured manometrically while flow rates were obtained from variable-area flow meters. The approximate location of the pressure taps for the measurement of supply, control and receiver pressures is shown in Fig. 1.

Experimental characteristics which have been obtained include supply, input, transfer, output, and noise characteristics. The range of variables investigated is presented in Table 1.

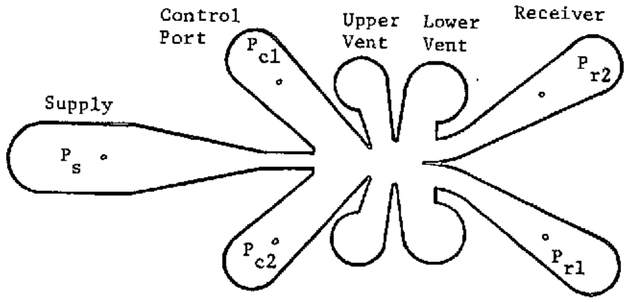

Figure 1 Schematic of Laminar Proportional Amplifier

TABLE I
Range of Variables Investigated

Aspect Ratio (H/W) (amplifier height/supply nozzle width)	0.5, 1.0, 1.4
Reynolds Number (VH/ν)	700 to 1400
Mean Control Pressure $P_{cm} = (P_{c1} + P_{c2})/2$	0 to 30% of Supply Pressure

Presented in this report is a small portion of the data taken showing typical characteristics and trends of the laminar proportional amplifier.

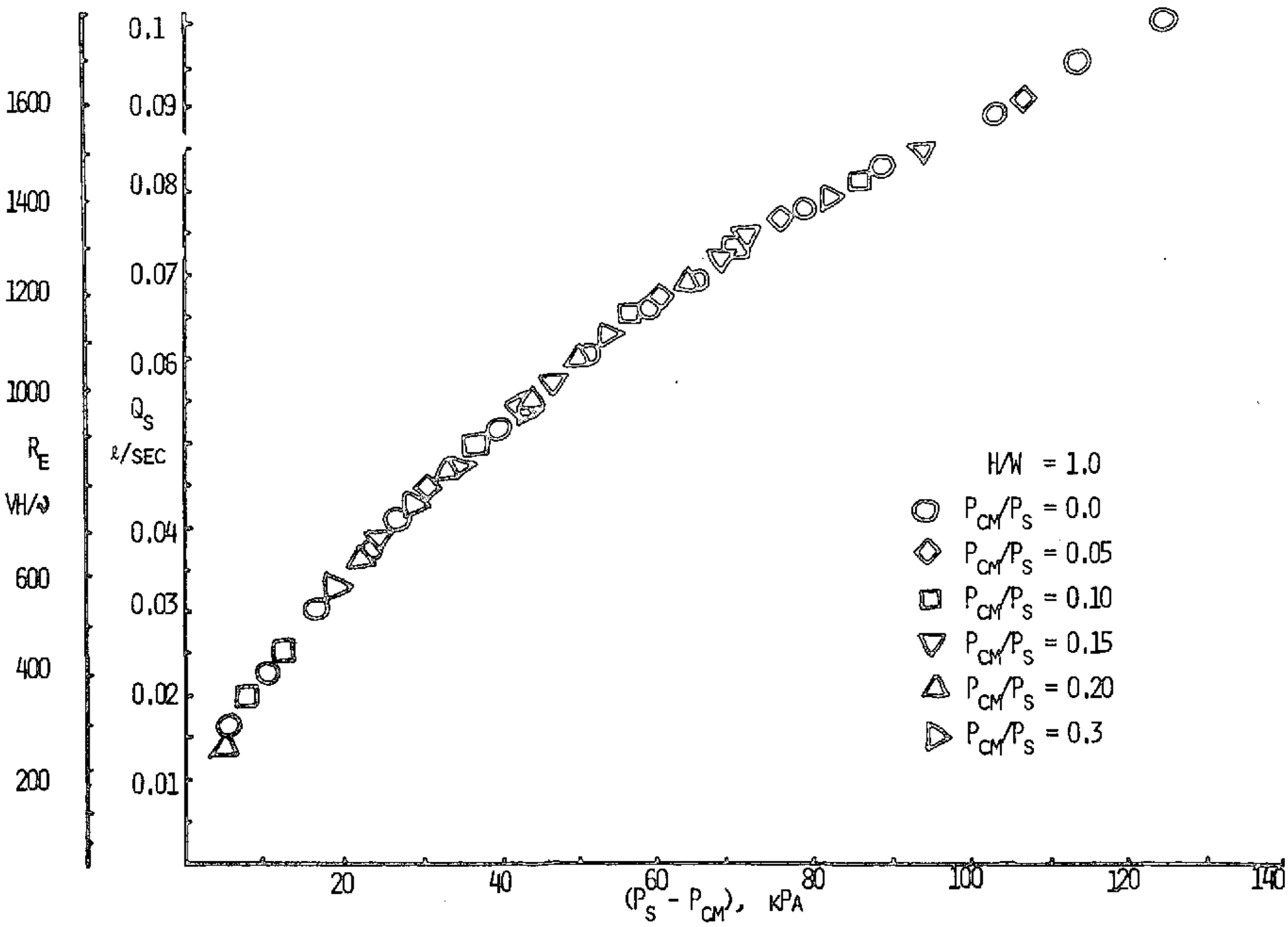

Figure 2 Supply Characteristics for an Aspect Ratio of 1 and Various Mean Control Pressures

In obtaining the supply characteristics, it was found that for a given aspect ratio the supply flow and, hence, the Reynolds number depended upon the difference between the supply pressure and the mean control pressure. Figure 2 presents the data for an aspect ratio of 1 and for mean control pressures of up to 30% of the supply pressure. By plotting the supply flow and Reynolds number versus the difference between the supply pressure and mean control pressure times the square of the aspect ratio, the supply characteristics for aspect ratios of 0.5, 1.0, and 1.4 collapse into a single curve as indicated in Fig. 3. Thus, for a given aspect ratio and mean control pressure one may easily obtain both the supply flow and Reynolds number for a given supply pressure or vice versa.

Data were taken on the input characteristics for aspect ratios of 0.5, 1.0, and 1.4 and for Reynolds numbers of approximately 700, 1050, and 1400. Figure 4 presents the input characteristics for an aspect ratio of 1 and a Reynolds number of 1100 as a plot of control flow versus control pressure normalized with respect to the supply flow and supply pressure respectively. Both null characteristics (i.e. $P_{c1} = P_{c2}$) and push-pull characteristics (i.e. $P_{c1} + P_{c2} =$ constant) are presented on this figure. Variations in both the null and push-pull characteristics over the previously mentioned aspect ratio range and Reynolds number range were found to be slight when control flow and control pressure were normalized with respect to the operating supply flow and pressure respectively. It should be mentioned that in taking this data the supply pressure was maintained constant which yielded a variation in the supply flow and Reynolds number with changing mean control pressure. The supply flow used in the normalization in Fig. 4 is that supply flow occurring for a zero mean control pressure.

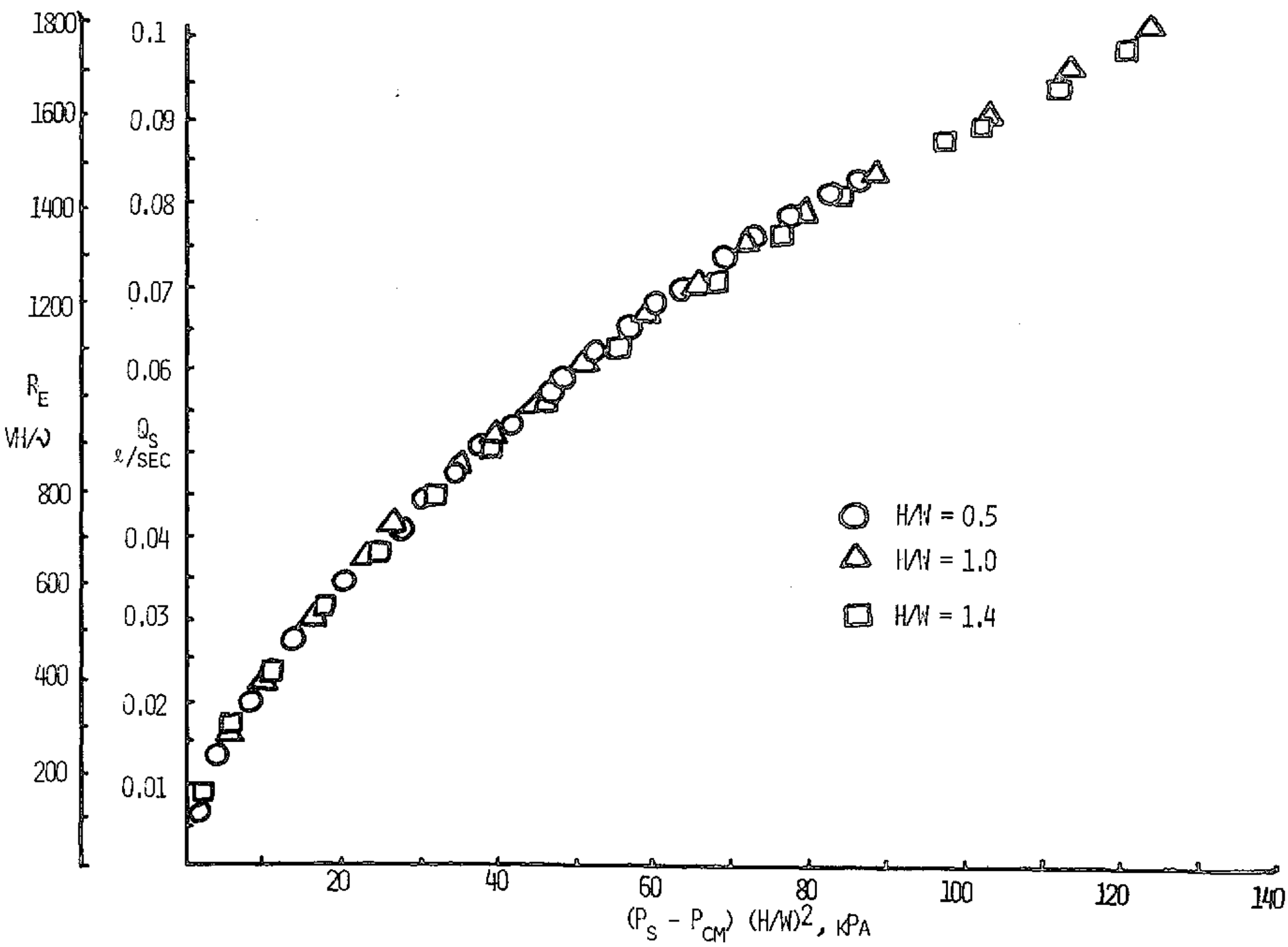

Figure 3 Supply Characteristics for Aspect Ratios of 0.5, 1.0, and 1.4

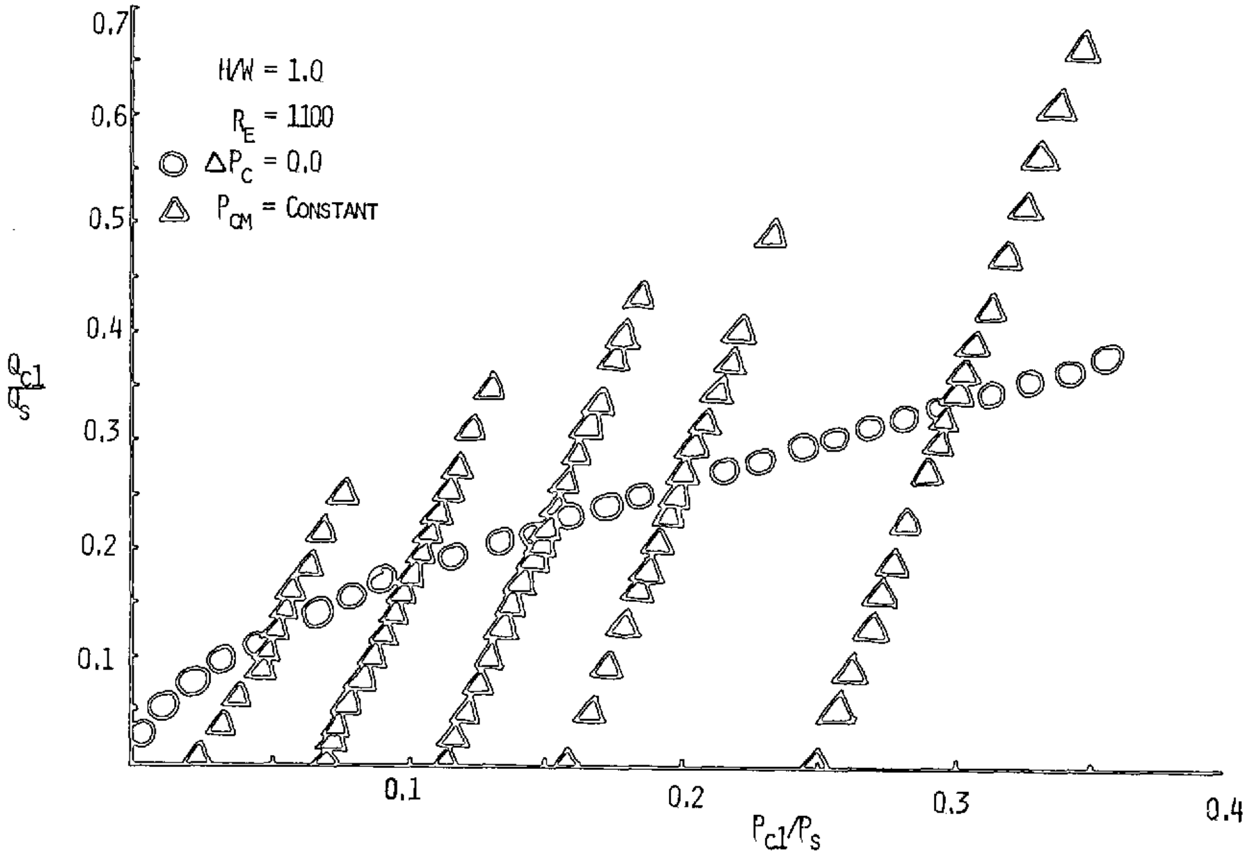

Figure 4 Input Characteristics for an Aspect Ratio of 1 and a Reynolds Number of 1100

Also of importance in describing the input characteristics of the laminar proportional amplifier is the degree of cross-coupling between the two control ports. One method of indicating the degree of cross-coupling is a plot of P_{c2} versus P_{c1} with Q_{c2} held constant for a particular mean control pressure, aspect ratio and Reynolds number. Figure 5 presents this data for an aspect ratio of 1, Reynolds number of 1100 and mean control pressures of 0, 10, 20, and 30% of the supply pressure. If the control ports were uncoupled one would obtain a line with zero slope since P_{c1} could be varied without changing P_{c2}. If P_{c2} versus P_{c1} yielded a line with a slope of 1, any change in P_{c1} would be accompanied by an equal change of P_{c2}. Thus, the slope of the data at a given mean control pressure is a measure of the degree of cross-coupling between the two control ports. It is not surprising that the device exhibits a fairly large degree of cross-coupling since the control port knife edge has a setback of only one half of the supply nozzle width.

Transfer characteristics were obtained for the aforementioned aspect ratio range, Reynolds number range and mean control pressure range. A typical set of these characteristics is shown in Fig. 6 for an aspect ratio of 1, mean control pressure of 10% of supply pressure and three operating supply pressures corresponding to three different Reynolds numbers. The data is presented in the form of blocked differential receiver pressure versus the differential push-pull control pressure. Both quantities are normalized with respect to the supply pressure. As is evident by this figure, the blocked load pressure gain of the laminar proportional amplifier is essentially the same for all three supply pressures, although the higher Reynolds numbers exhibit a larger operating range. The device also possesses good saturation characteristics. It was found that the gain of each aspect ratio tested was independent of the Reynolds number (over the aforementioned range) for mean control pressures of up to 20% of the supply pressure. Above this value the gain was found to vary with Reynolds number with the higher Reynolds numbers having the larger gain. However, it was found that the gain of the device was strongly dependent upon the mean control pressure. This is shown in Fig. 7 as a plot of the normalized differential receiver pressure versus the normalized differential mean control pressure for an aspect ratio of 0.5 and a Reynolds number of 720. As is seen, the pressure gain of the device decreases with increasing control pressure.

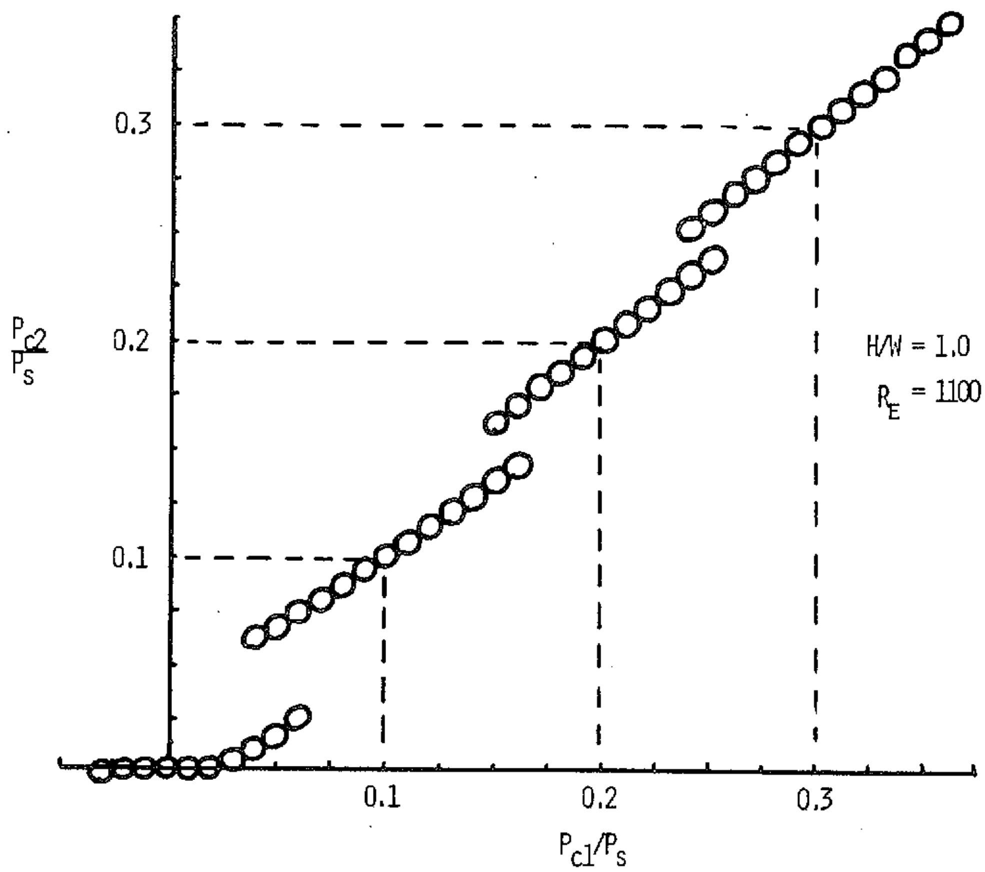

Figure 5 Cross-Coupling between Control Ports

In obtaining data on the output characteristics of the laminar proportional amplifier, it was determined that considerable loading effects were present. Therefore, four different loading conditions were investigated. These four cases are described below:

Case I. This loading condition corresponded to the case of one output port blocked while the output through the other port was modulated by changing the opening of a needle valve.

CASE II. For this case one output port was "open" while the other was modulated by a needle valve. The fixed loading on the output port called "open" was defined for null (i.e. $\Delta P_c = 0$) conditions as the load required for the flow through the "open" port to equal the flow through the modulated port when the needle valve was fully open.

CASE III. This loading condition corresponded to the case when the unmodulated outport port resistance was set at a "nominal" load and the other output port was modulated by a needle valve. This "nominal" load was defined for null conditions as the load required for the flow through both ports to be equal when the modulated port was set at the load required for the receiver pressure to equal approximately 70% of the blocked load pressure.

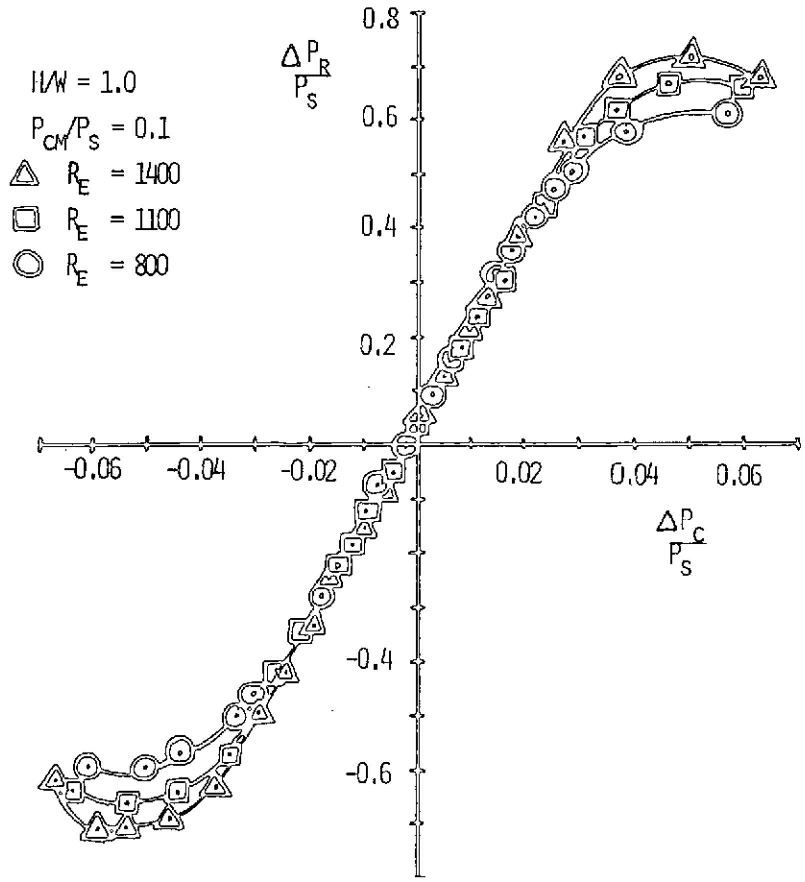

Figure 6 Transfer Characteristics for an Aspect Ratio of 1 and Various Reynolds Numbers

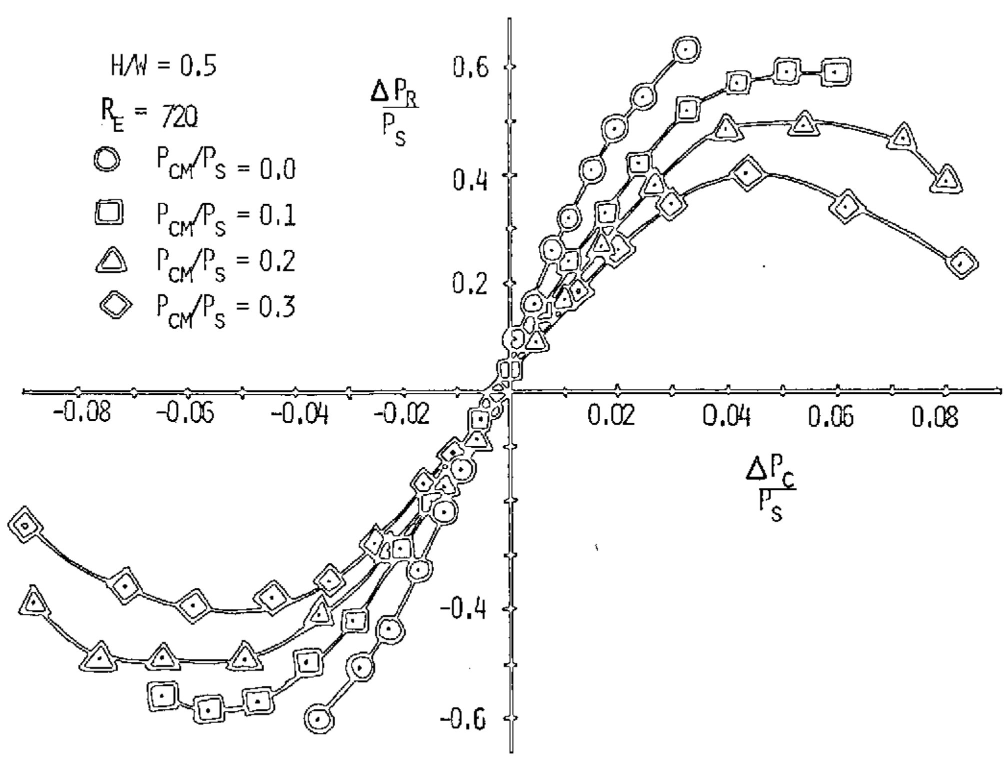

Figure 7 Transfer Characteristics for an Aspect Ratio of 0.5 and Various Mean Control Pressures

CASE IV For this loading condition the flows through the output ports were modulated so that they were always equal under null conditions.

Figure 8 presents the output characteristics for an aspect ratio of 1.0, Reynolds number of 700, mean control pressure of 10% of supply pressure, Case III loading, and for various values of the differential push-pull control pressure. This data in the form of normalized output flow versus receiver pressure indicates a low output impedance especially for larger loads.

Space does not permit detailed data presentation of the effects of aspect ratio, Reynolds number, mean control pressure and loading on the output characteristics. However, general observations which can be made about the output characteristics are: 1) appreciable coupling exists between the output ports, 2) receiver pressure recovery increases with increasing mean control pressure, supply pressure (or Reynolds number), and/or aspect ratio, 3) output oscillations become pronounced for supply Reynolds numbers above 1300, 4) output impedance decreases with increasing aspect ratio, 5) anomalies in the output characteristics occur under certain conditions which appear to be at least functions of the output loading, mean control pressure, supply pressure and aspect ratio.

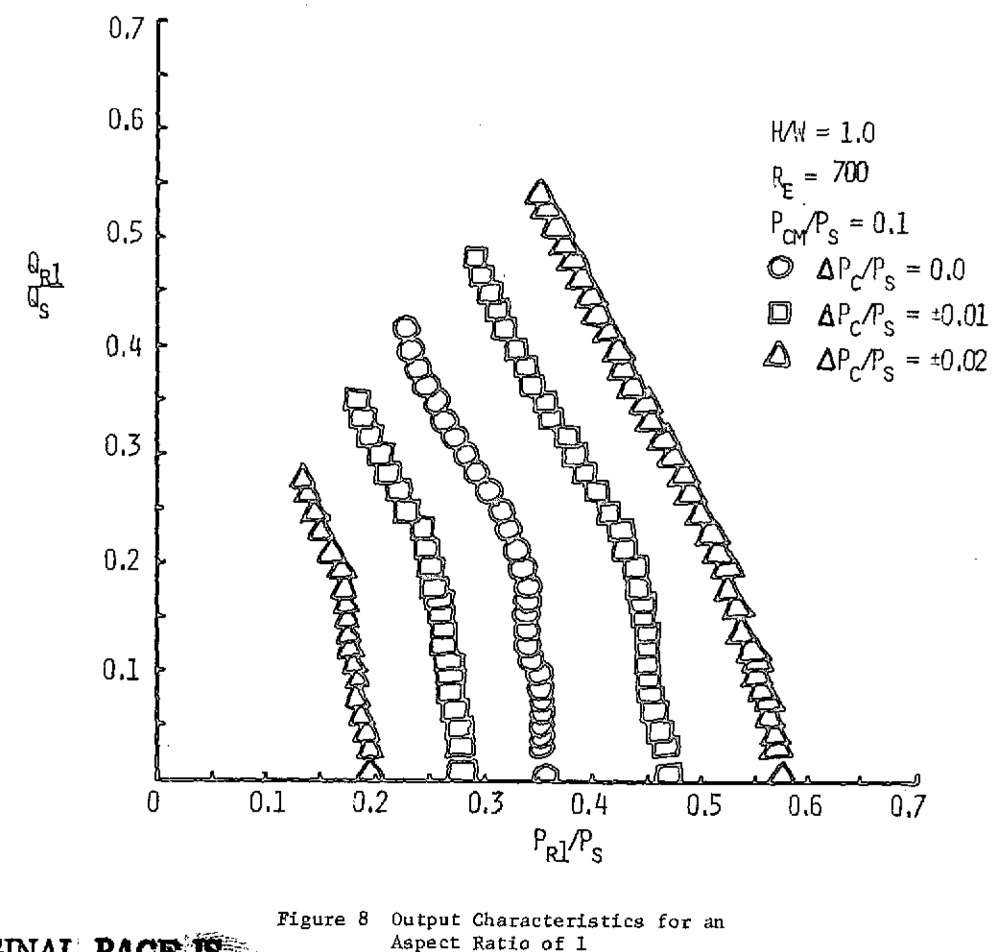

Figure 8 Output Characteristics for an Aspect Ratio of 1

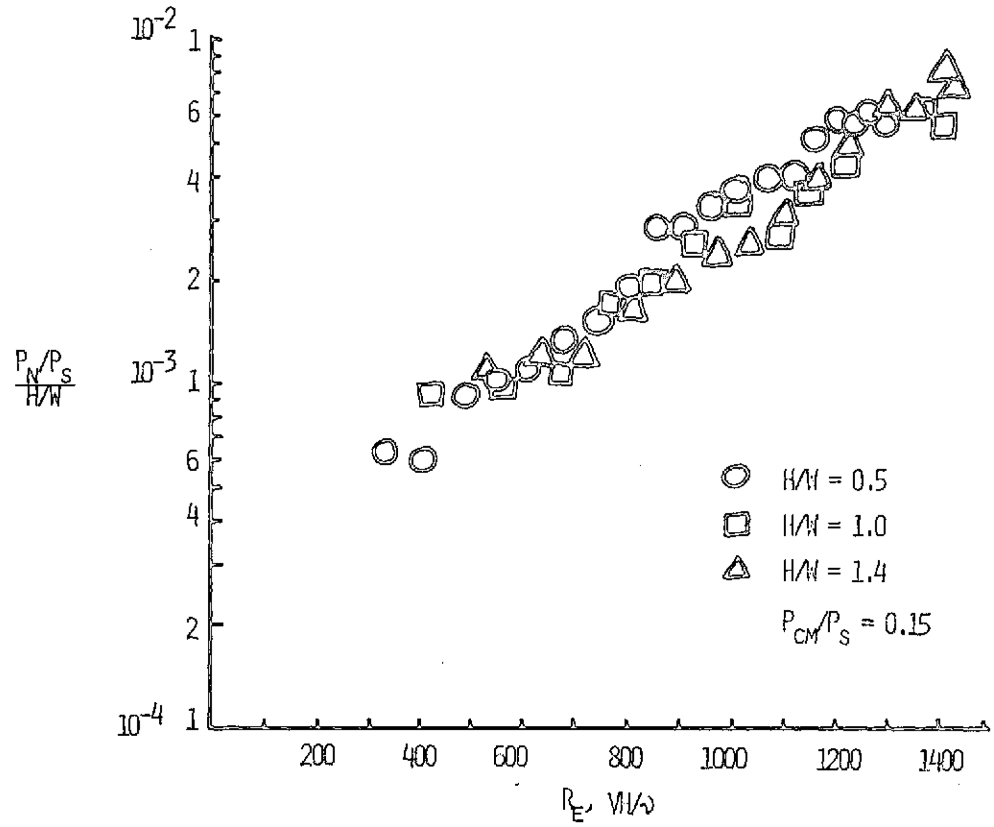

Figure 9 Differential Receiver Noise Characteristics

The differential receiver pressure noise characteristics of the laminar proportional amplifier as a function of aspect ratio, Reynolds number and mean control pressure were also investigated. Power spectral densities of the noise were obtained for the previously mentioned aspect ratio range and Reynolds number range. Figure 9 is a plot of the true RMS value of the normalized differential receiver noise divided by the aspect ratio versus the actual supply Reynolds number for aspect ratios of 0.5, 1.0, and 1.4 and a mean control pressure of 15% of the supply pressure. From this figure it appears that the noise is proportional to the aspect ratio and increases with increasing Reynolds number. This data was obtained for a bandwidth of 200 Hz, for zero differential control pressure, and for blocked outputs.

Current work on the laminar amplifier is involved with the analytical prediction of amplifier characteristics as well as experimental measurements of dynamic performance.

This work has been supported primarily by DOD Contract No. DAAG 39-73-C-0213, having been initiated by support from NASA Grant NGR 39-009-023.

VELOCITY PROFILES FOR LAMINAR FLUIDIC JETS

John Hochstein, Graduate Assistant in M. E.

In recent years an interest in operating fluidic devices with laminar flow has developed. A major advantage of operating in the laminar regime, as opposed to the turbulent regime, is the possibility of attaining a steeper velocity profile due to less entrainment of surrounding fluid. This will result in the ability to achieve higher amplifier gains. Another obvious advantage is that less energy will be required to drive the system since the velocities required are lower. The laminar jet is more suited to pressure-field switching which may prove to be another advantage. Another advantage is decreased noise levels.

The purpose of this research is to determine the actual velocity profiles downstream of a typical laminar fluidic jet and to develop an analytical method of predicting them. A large scale model with an aspect ratio of one and a nozzle width of 12.7 mm is being used in order to achieve sufficient spatial resolution of the flow measuring sensor. Figure 10 is a schematic of the experimental apparatus.

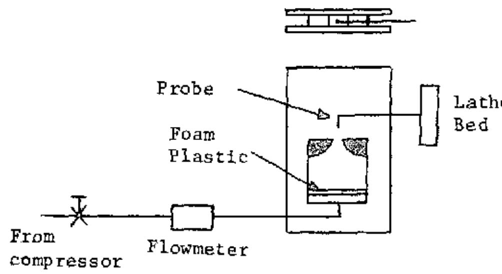

Figure 10 Experimental Set-up Employed to Make Velocity Profile Measurements

A hot wire anemometer has been selected as the fluid velocity sensing device and air as the medium. The hot-wire was selected for two main reasons. First it is capable of measuring low velocities (i.e. .3m/sec) which other devices, such as a pitot tube, are not capable of doing. Secondly, the probe is of sufficiently small size to obtain adequate spatial resolution without an excessively large jet. A trade-off in jet size was necessary since a larger jet would improve spatial resolution but would also lower the maximum velocity at which laminar flow could be assured. Since a jet of 12.7 mm width was necessary to obtain the desired resolution, velocities down to 0.03 m/sec must be measured. This presents a significant problem since at these velocities the hot-wire heat transfer characteristics may no longer be considered to be dominated by forced convection relative to natural convection effects. Thus a linearizer is not being used since the simple relations for higher velocity measurement no longer hold. The apparatus has been arranged in a vertical manner in order to align the natural and forced convection effects. It has been found [17] that such an alignment will allow a more accurate measurement of velocities in this low range. Work-to-date has shown that such an alignment will allow measurement of velocities down to 0.03m/sec with excellent repeatability.

A stilling chamber has been provided to smooth the flow before it enters the nozzle to provide a smooth velocity profile leaving the jet. The hot-wire will be traversed through the velocity field with the aid of a bench lathe cross-feed mechanism attached to the jet stand.

The goal is to compare experimentally obtained velocity profiles with analytically predicted profiles. The two analytical solutions which will be involved are the solution for a free two-dimensional laminar jet issuing from an infinitely narrow slit and the solution for the mixing of two parallel laminar streams of different velocities.

This work has been supported partly by NASA Grant NGR 39-009-023.

SPEED CONTROL SYSTEM EMPLOYING A JET PIPE VALVE

Tran-Cam-Huan, Graduate Student in M. E.

An M. S. thesis entitled, "Use of the Jet-Pipe Valve in a Speed Control System" has been completed by Mr. Tran-Cam-Huan. The following abstract is taken from this thesis:

"An analytical and experimental investigation of a speed regulation system for steam turbines is presented. An actual control system, employing an electronic controller and a pneumatic actuator, was studied experimentally. A wave generator driven by a steam valve positioner with an intermediate driving bar and pully system was found to simulate satisfactorily the function of the steam turbine in the laboratory tests, giving a useful speed signal in the form of a frequency-modulated sinusoidal wave.

The main focus of the study centered on investigation of the jet-pipe valve. Predicted and measured characteristics were compared revealing some deficiencies in design of components. The design of the receiver block assembly was revised to eliminate leakage between the receiver passages, making it possible to achieve the predicted characteristics, obtained from earlier work by K. N. Reid and associates at M.I.T.

Some deficiencies were found also in the electronic controller, especially in the derivative part of the P.I.D. (proportional-plus-integral-plus-derivative) controller and in the set-point circuit.

During these experiments the P.I.D. controller output revealed P.I. (proportional-plus-integral) control, but the expected derivative action was absent. However, a unit which was supplied later in the program did have the derivative action.

Based on a brief analysis of the electronic control circuit, suggested modifications have been proposed. However, limitations of time and money prevented their implementation.

Successful operation in the laboratory with compressed air was achieved during brief closed loop tests with the modified jet-pipe valve and P.I. control, using a DC signal for set-point adjustment."

This work was accomplished with the help of an A.I.D. Fellowship.

POWER AMPLIFICATION WITH A VORTEX VALVE

William D. Mangieri, Graduate Assistant in M. E.

An M. S. thesis by William D. Mangieri, graduate student in M. E., has been completed having the above title [18]. In this thesis the characteristics of a vortex valve, operating with variable upstream pressure and fixed downstream pressure, are presented. This data is needed in order to be able to use the vortex valve in combination with a fixed upstream resistance as a fluidic flow amplifier. A typical set of output pressure vs. output flow curves for such a vortex valve are shown in SCL Report No. 16, along with the curve for a fixed upstream orifice [16].

Input pressure vs. flowrate curves were also obtained for this valve in order to design proper drive conditions at the point. A typical family of input characteristics is shown in Fig. 11

Exploratory tests were also run using the vortex valve as the only variable resistor in a four-arm bridge to drive a double-acting pneumatic ram in open loop fashion, with reasonable success.

When opposing input-controls were used however, to achieve a summing effect at the valve input, it was found that control port interaction is so strong that it could not be used as a summer when operated with variable upstream pressure.

This work has been supported by NASA Grant NGR 39-009-023.

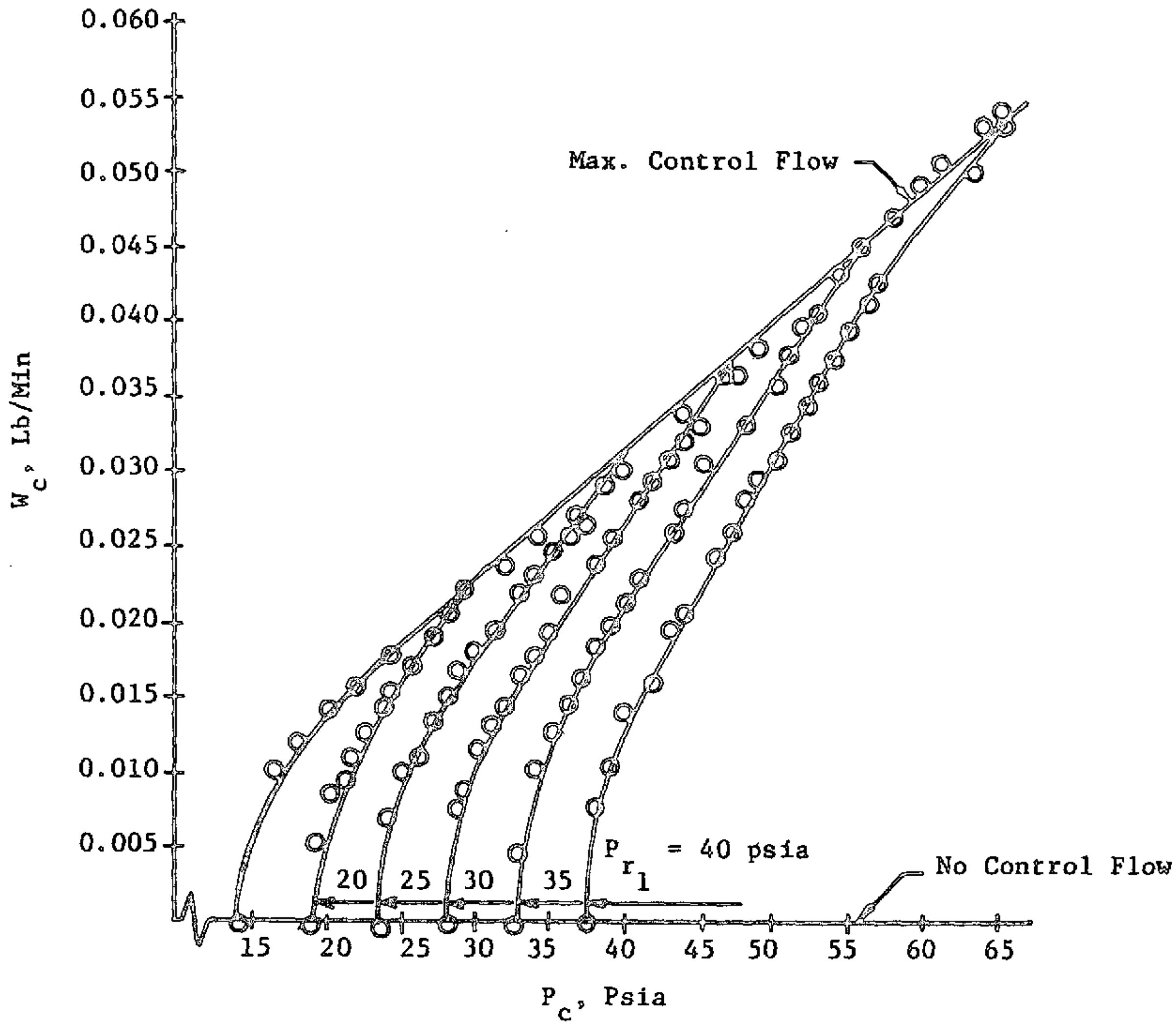

Figure 11 Input Pressure-Flowrate Curves for Vortex Valve

TEN-YEAR SUMMARY OF THESES COMPLETED IN THE SYSTEMS AND CONTROLS LABORATORY

The following chronological list has been prepared to summarize the thesis research that has been conducted in the Systems and Controls Laboratory during the past ten years.

Author	Title of Thesis, Date, etc.	Financial Support
Elia, Frederick J.	"A Pneumatic Function Generator", M.S. in M.E., June 1965	Mech. Eng. Dept.
Ruppert, David L.	"Simulated Response of a Hydraulic Stepping Motor", M.S. in M.E., June 1965	NASA (part)
Herritt, Hal H.	"Control of Closed Loop Systems Having Dead Time", M.S. in M.E., Sept. 1965	Ordnance Research Lab.
Martin, Raymond P.	"A Pneumatic Stepping Motor", M.S. in M.E, Dec. 1965	NASA
Harper, Richard T.	"An Application of the Free Piston Principle to Steam Powered Air Compression", M.S. in M.E., Sept. 1966	Ordnance Research Lab.
Justice, Malcolm C.	"The Design of a Low-Inertia, Shell-Type, D-C Motor", M.S. in M.E., Dec. 1967	NASA
Tamulis, John C.	"Sources of Signal Noise in Fluid Amplifiers", Ph.D. in M.E., Dec. 1967	NASA IBM Fellowship
Bettoli, Roberto	"Experimental Study of Spreading of Semi-Confined Jets (Turbulent Mixing Between Flat Plates of a Submerged Jet Formed by Rectangular Cross Section Nozzle with Particular Emphasis on Applications in Fluidics)", M.S. in M.E., March 1968	NASA
Tomek, Reinhold E.	"Thermal Separation Control Applied to Electro-Fluidic Switching in a Straight Walled Diffuser", Ph.D. in M.E., Sept. 1968	NASA IBM Fellowship
Stone, Michael	"Design and Implementation of a Real-Time Data Acquisition System", M.S. in M.E., Dec. 1968	PDP-9 Computer
Gray, Richard W.	"Effects of Upstream Disturbance Intensities on the Spreading of a Semi-Confined Jet", M.S. in M.E., June 1969	NASA
Song, Moon-Bum	"Experimental Study of an Oscillating Vane-Digital Flow Rate Sensor", M.S. in M.E., June 1969	NASA USAF Fellowship
Carlson, Robert J.	"The Frequency Response of Pneumatic Transmission Lines of Rectangular and Round Cross-Sections", M.S. in M.E., June 1970	Bell Telephone Labs.
Leonard, Robert G.	"A Simplified Model for a Fluid Transmission Line", Ph.D. in M.E., June 1970	Small Industries Research
Gillespie, Thomas D.	"An Analytical and Experimental Study of the Influence of Swirl on Choked Nozzle Flow", Ph.D. in M.E., Dec. 1970	NASA
Stabley, Robert E.	"Self-Optimization of a Simulated Prime Mover Employing Electrohydraulic Actuation", M.S. in M.E., Dec. 1970	NASA
Huber, Robert R.	"Modeling Surges in Liquid Filled Lines", M.S. in M.E., March 1971	Small Industries Research NASA (part)

TEN-YEAR SUMMARY OF THESES COMPLETED IN THE SYSTEMS AND CONTROLS LABORATORY (Cont'd.)

Author	Title of Thesis, Date, etc.	Financial Support
Mayne, Roger W.	"Study of Simple Extremum Controllers Emphasizing Fluidic Implementation", Ph.D. in M.E., March 1971	NDEA Fellowship NASA (part), Optimal Control Corp.
Fahnestock, Melvin R.	"Investigation of a Bistable Fluidic Amplifier Operating with Liquids at Low Reynolds Numbers", M.S. in M.E., June 1971	Small Industries Research NASA
Knopp, Arthur A.	"A Study of Receiver Pressure-Flow and Vent Flow Characteristics of a Fluidic Rectifier", M.S. in M.E., June 1971	ARO
Landsburg, Kurt	"Loading Effects on the Response of an Analog Fluid Amplifier", M.S. in M.E., June 1971	NASA (part) NSF Faculty Initiation Grant
Gaskill, George	"The Experimental Development of a Hydraulic Stepping Motor", M.S. in M.E., Sept. 1971	NASA
Stiffler, Alan K.	"Sinusoidal Excitation of a Free Turbulent Jet", Ph.D. in M.E., Sept. 1971	NASA & United Aircraft
Boal, Dilip K.	"Investigation of a Fluidic-Rectifier-Type FM-to-DC Signal Conversion System, M.S. in M.E., Dec. 1972	ARO (part)
Mangieri, William M.	"Power Amplification with a Vortex Valve", M.S. in M.E., Nov. 1974	NASA
Tran-Cam-Huan	"Use of the Jet-Pipe Valve in a Speed Control System", M.S. in M.E., Nov. 1974	A.I.D.
Fowler, Donald W.	"Response of Fluidic Systems to Alternating Signals", M.S. in M.E., (in draft form)	National Science Foundation

For further information about the projects mentioned in this report or the activities of the Systems and Controls Laboratory, inquiries should be addressed to: Director, Systems and Controls Laboratory, 214 Mechanical Engineering Building, University Park, PA 16802.

LIST OF REFERENCES

1 - 16 Research Reports Nos. 1 - 16, Systems and Controls Laboratory, The Pennsylvania State University, Semi-Annual Reports, April 1965-July 1973.

17. "Low Velocity Measurement", Bulletin TB14, Thermo Systems, Inc.

18. Mangieri, W. M., "Power Amplification with a Vortex Valve", M. S. Thesis, The Pennsylvania State University, Nov. 1974.